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INVESTIGATION OF CONCRETE DETERIORATION IN CERTAIN BRIDGES IN THE ROCHESTER, NEW YORK AREA

Special Investigation

Physical Research Project No. 24
Field Evaluation of Portland Cement Concrete

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NEW YORK STATE DEPARTMENT OF PUBLIC WORKS

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U.S. DEPARTMENT OF COMMERCE

BUREAU OF PUBLIC ROADS

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INTRODUCTION

In October, 1962 the Bureau of Physical Research was requested by Mr. B. F. Perry, District Engineer, to examine concrete deterioration occurring in several bridge structures located in the Rochester, New York area. The purpose of this examination was to determine the probable causes of distress and to recommend remedial and preventive measures.

Seven bridges were noted by district personnel as exhibiting various degrees of concrete weathering, as follows:

(1) Troup Street - Howell Street, FAGC 53-11
(2) Mt. Read Blvd. over N.Y.C. RR, FASH 53-4P
(3) Mt. Read Blvd. under B & O RR, FASH 53-4P
(4) Mt. Read Blvd. under Ridgeway Ave., FASH 53-4P
(5) Mt. Read Blvd. under Ridge Rd., FASH 53-4P
(6) Inner Loop at Monroe Ave., FAC 56-3
(7) Oak St. over Tonawanda Cr., FAC 52-14 (Batavia N. Y.)

Bridges (1) through (5) are located within the City of Rochester and were built during 1954-55 with coarse aggregate obtained locally from Quarry 4-6R. Bridge (6) is also within the city limits but was constructed more recently. The coarse aggregate in this structure was supplied by another local source, Quarry 4-4R. Bridge (7) is located in Batavia, New York and was constructed during 1954-55 with coarse aggregate from Quarry 4-3R.

The two quarries that supplied the six structures in Rochester currently operate exclusively in the Lockport dolomite formation. However, during the period when bridges (1) through (5) were constructed, Quarry 4-6R occasionally penetrated the underlying De Cew formation. The De Cew, which has not been exposed in Quarry 4-4R, is a transitional argillaceous dolomite that grades into the Rochester shale. While the De Cew is no longer acceptable as a source of coarse aggregate, its use at that time is suspected by some as being the cause of the

less durable concrete made with aggregate from Quarry 4-6R prior to about 1957, as compared to concrete made with aggregate from Quarry 4-4R. The variable characteristics of the De Cew and its intermittent use may also explain why some structures built during the 1954-55 period with aggregate from Quarry 4-6R have been reported as exhibiting little or no deterioration. In addition, the frequent appearance of "dirty" aggregate in stockpiled material from Quarry 4-6R has been a cause for concern by some district personnel. The last structure, bridge (7), was included in this investigation at the special request of District Engineer Perry, even though the coarse aggregate is Onondaga limestone obtained from Quarry 4-3R.

INVESTIGATION

This report summarizes information relative to the Rochester bridges that has been gathered from several sources. The on-site observations were made by District and Physical Research personnel; the laboratory examinations by the Bureaus of Physical Research and Materials, and by the Geology Department of Rensselaer Polytechnic Institute.

Field Observations

Prior to this investigation, observations by Mr. Pratuch of the District office established that the concrete deterioration noted on these bridges had commenced at least as early as 1960, and undoubtedly before. The Troup Street - Howell Street Bridge was undergoing major repair during 1959 and it is presumed that signs of distress first appeared some years prior to that time. Distress of a similar nature has been observed by Mr. Pratuch in bridge structures in other parts of the District. Further, he suggested the possibility of a chemical reaction between coarse aggregate and cement alkalies as the cause of deterioration.

A detailed inspection was made of each bridge in November of 1962 by engineers of the Bureau of Physical Research. During this inspection, locations were designated for the removal of cores which were taken approximately two weeks later. The condition of each structure at that time was as follows:

Troup Street - Howell Street - Concrete deterioration has been extensive throughout the structure. Major repairs had been made to the deck which involved removal and replacement of unsound concrete. The structural deck, curbs, and walkways had been sealed with an epoxy membrane. The deck had been further covered with a bituminous wearing surface. Deck concrete that had not been removed at the time of repair is now showing signs of disintegration as viewed from the underside. When coring was attemped through portions of the original deck, disintegrated concrete was encountered. This suggests that water has had access to this area, perhaps through the wearing surface from above, as this portion is presumed to have been in good condition at the time of repair.

The piers and abutments had been extensively patched, but showed signs of continuing disintegration. Concrete distress in the understructure was, and has been, most prevalent where water has drained from the deck over pier headers and footings (Figure 1).

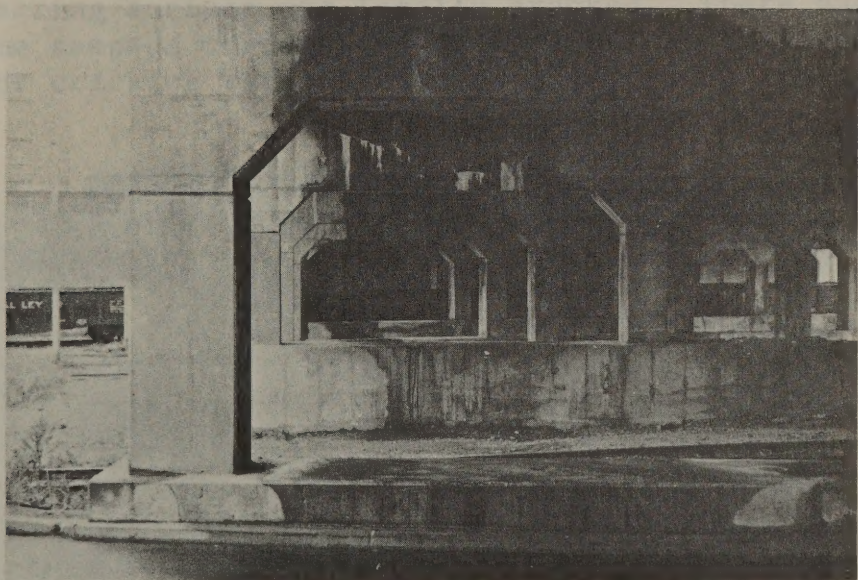

Figure 1 - Troup St. - Howell St. Bridge
Looking east from Pier F

Extensive patching of headers and footings has been necessary in nearly every bay. The light colored material seen in Figure 1 exuding from cracks in Pier E was frequently observed in areas of distressed concrete. Chemical analysis of this material indicates that it is principally calcium carbonate with some sodium chloride. Light brown stains were noticed on some concrete of this bridge as well as on others. These stains were noted only in areas exposed to moisture and frequently in association with incipient cracking. No significance was attached to these other than the fact that they indicated the presence of iron compounds in the drainage.

Mount Read Blvd. over N.Y.C. RR - The east sidewalk and curb previously had deteriorated to the point where surfacing with a bituminous mix had been required. The east facia (Figure 2) was also severely damaged and showed abundant water stains. The west curb, sidewalk, and facia, on the other hand, were relatively free from damage. The concrete median island had scaled to a moderate degree.

Ponded water was observed on the bridge deck, and the bituminous wearing surface was locally cracked. There had apparently been some seepage through the deck as evidenced by water stains and minor cracking beneath reinforcing bars on the underside.

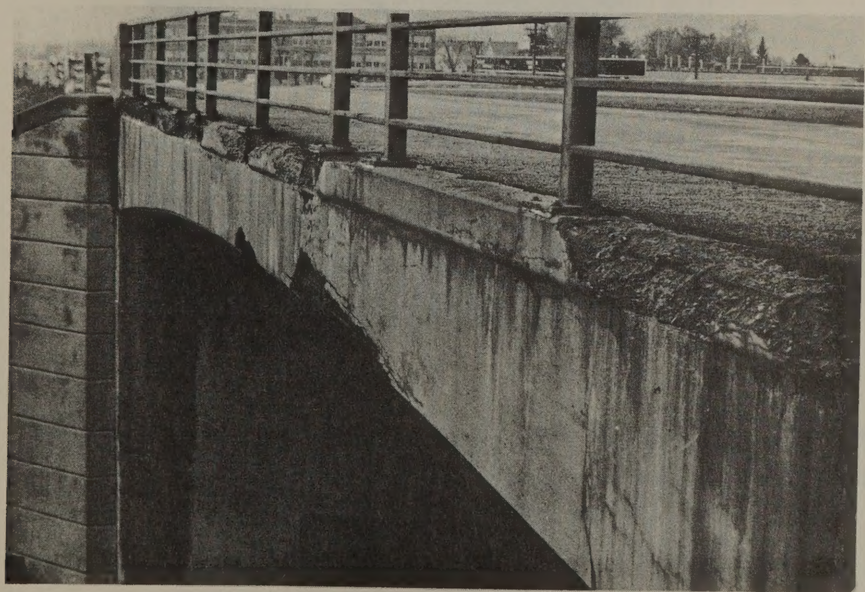

Figure 2 - Mt. Read Blvd. over N.Y.C. RR
Looking south along east facia

Extensive patching of headers and footings has been necessary in nearly every bay. The light colored material seen in Figure 1 exuding from cracks in Pier 2 was frequently observed in areas of distressed concrete. Chemical analysis of this material indicates that it is principally calcium carbonate with some sodium chloride. Light brown stains were noticed on some concrete of this bridge as well as on others. These stains were noted only in areas exposed to deicers and frequently in association with horizontal-plane cracking. No significance was attached to these other than the fact that they indicated the presence of iron compounds in the drainage.

<u>Mount Read Blvd. over N.Y.C. RR</u> - The east sidewalk and curb previously had deteriorated to the point where surfacing with a bituminous mix had been required. The east fascia (Figure 2) was also severely damaged and showed abundant water stains. The west curb, sidewalk, and fascia, on the other hand, were relatively free from damage. The concrete median island had scaled to a moderate degree.

Ponded water was observed on the bridge deck, and the bituminous wearing surface was locally cracked. There had apparently been some seepage through the deck as evidenced by water stains and plane cracking beneath reinforcing bars on the underside.

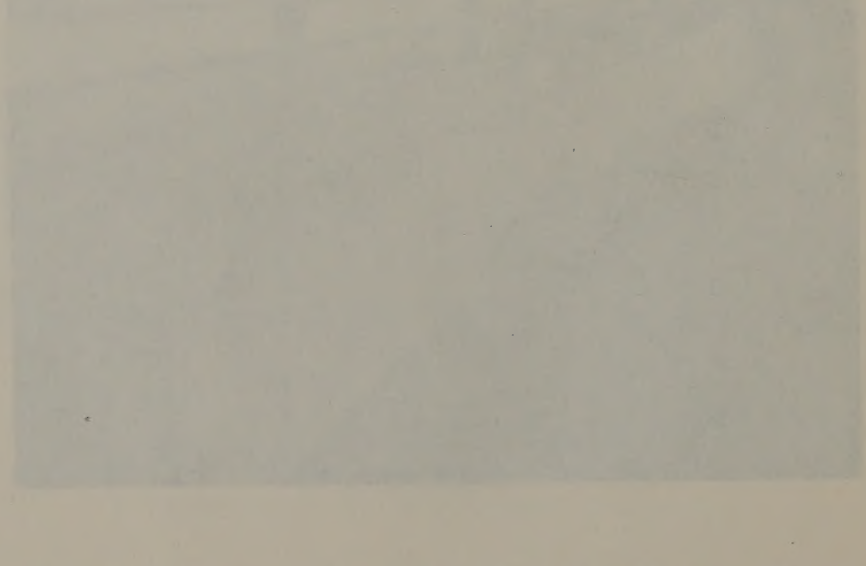

Figure 2 - Mt. Read Blvd. over N.Y.C. RR
Looking south along east fascia

In general, the abutments and wing walls were in excellent condition, except for some cracking on the east side of the south abutment (Figure 3). As with the Troup St. - Howell St. Bridge, most deterioration was associated with the presence of an abundance of water. Some pitting was observed in association with what appeared to be a red sandstone fine aggregate. This was particularly evident on the east end of the north abutment.

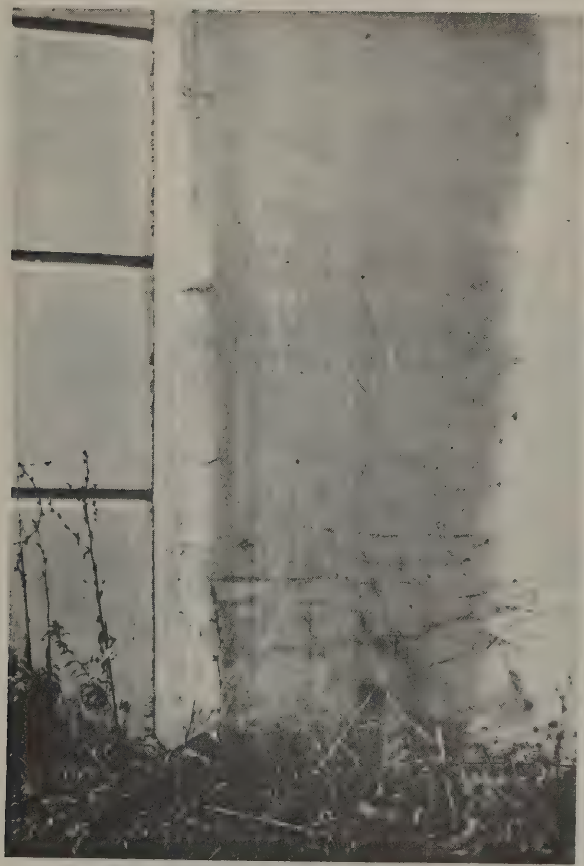

Figure 3 - Mt. Read Blvd. Br. over N.Y.C. RR
View of east end of south abutment
adjacent to wing wall.

Mount Read Blvd. under B & O RR - In general, this bridge was in very good condition. Three small areas of scaling were observed adjacent to joints in the sidewalk retaining wall. The largest of these areas is shown in Figure 4. All scaled areas were in the path of water which was observed flowing across the sidewalk and down the face of the wall. In contrast to this, where drainage was evident over the face of the abutment (as seen in Figure 4 behind the railing), no distress was noted. Small areas of incipient cracking were observed in the northwest wing wall and in the center pier. A few popouts of a laminated coarse aggregate were observed in the sidewalk retaining walls. The almost complete absence of distress in the abutments pier and wing walls may be due to the fact that it is a railroad overpass with the consequent absence of deicing chemicals in water that drains from above. The sidewalk retaining walls, on the other hand, are adjacent to the roadway and are undoubtedly salted by splashing.

Figure 4 - Mt. Read Blvd. Br. under B & O RR
View of east sidewalk retaining wall.

Mount Read Blvd. under Ridgeway Ave. - The deck of this bridge was in fairly good condition, except for some damage adjacent to transverse joints noticeable from beneath. Portions of the sidewalk and facia had been patched. The north facia was stained and had begun to scale adjacent to the deck joint. When the deck was cored near the joint, the surface of the structural slab beneath the asphalt wearing surface was observed to be deteriorated. The pier, which is located directly beneath the deck joint had been patched, but signs of new distress were evident (Figure 5). The abutments have been extensively damaged where water has drained through the joint between the deck and approach slabs and between the deck and wing walls (Figure 6).

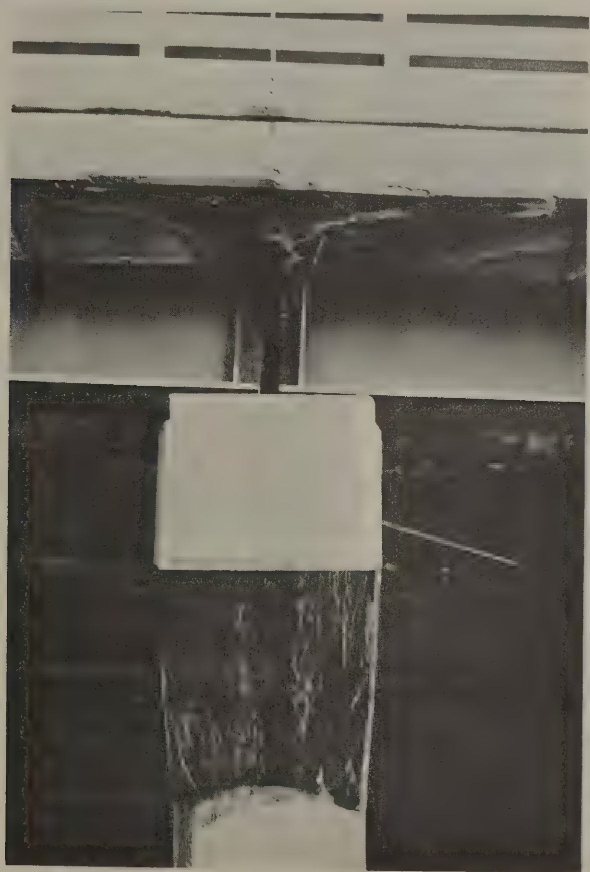

Figure 5 - Mt. Read Blvd. under Ridgeway Ave.
South face of center pier.

Figure 6 - Mt. Read Blvd. under Ridgeway Ave.
North end of west abutment

The northwest wing wall was in particularly poor condition (Figure 7). The white to gray colored deposits of calcium carbonate and sodium chloride noted on the Troup St. - Howell St. Bridge were particularly evident along the abutment back walls in association with severe disintegration. A small number of coarse aggregate popouts also were observed.

Mount Read Blvd. under Ridge Rd. - The general condition of this bridge was very similar to that at Ridgeway Ave. The deck, facia, wing walls and abutment back walls were damaged in the same way and to about the same degree. Cores taken through the deck also showed signs of scaling on their surface beneath the bituminous wearing course. The one notable exception to this was the piers which were in excellent condition. In this case, deck slabs are continuous over their supports and water draining through the joint had not, therefore, come in contact with the piers (Figure 8). Ponding of water over the expansion joint between the deck and approach slabs was observed both at the Ridge Rd. and Ridgeway Ave. structures. This appears to be the principal source of water that drains through these joints onto the abutment back wall.

Figure 7 - Mt. Read Blvd. under Ridgeway Ave.
Northwest wing wall.

Figure 8 - Mt. Read Blvd. under Ridge Rd.
View of east pier. Compare with
Figure 5 which shows a bridge pier
located beneath a deck joint.

Inner Loop at Monroe Ave. - Deterioration of structural concrete at this site has been restricted almost entirely to the retaining wall cap. Its appearance was similar to that observed in the other structures, being general disintegration of the paste from the surface inward. Some evidence of staining and incipient cracking were noticed at a few places on the retaining wall face and a few shallow popouts were observed.

Oak St. over Tonawanda Cr. (Batavia) - Concrete deterioration in this structure was very similar to that observed in bridges (1) through (5) in Rochester, however, more shallow popouts were noted, particularly in the piers. A particle of chert was observed to be at the base of many of these popouts.

Figure 9 - Oak St. over Tonawanda Cr., Batavia
East end of south pier.

At the time of inspection, a two to three foot diameter hole in the south bound lane of the deck had been covered with a steel plate. The facia was scaled adjacent to the deck joints and many popouts were observed where water had drained through these joints onto the piers (Figure 9). The popouts that could be examined appeared to be associated with pieces of chert.

Other Bridges in Monroe Co. - Attention has been drawn to the possibility that poor performance of concrete in the Rochester area has been caused primarily by aggregate from Quarry 4-6R. To check this belief and to examine the condition of air entrained concrete containing aggregate from this source, a visit was made to all other bridges in Monroe County known to have been constructed with the 4-6R or 4-4R coarse aggregates under Public Works contracts let between 1950 and 1960. A total of 49 additional bridges were inspected. Eleven were built with 4-6R aggregate, two of which incorporated air entraining cement. Thirty-nine were built with 4-4R aggregate including 16 which were air entrained. The condition of these structures, plus bridges (1) through (6) previously described, are summarized in Table 1.

TABLE I

CONDITION OF BRIDGES IN MONROE CO.
INCORPORATING 4-6R AND 4-4R AGGREGATE

		Source 4-6R	Source 4-4R	Totals
Non-AE	Distress (of varying degrees)	8*	19	27
	No Distress	6	4	10
AE	Distress (of varying degrees)	0	1+	1
	No Distress	2	16	18
TOTALS		16	40	

* Includes bridges (1) thru (5) previously discussed.
\+ Bridge (6) previously discussed.

In all cases where distress was observed, it had the same general characteristics as that noted in the Mt. Read Blvd. structures, bridges (2) - (5), except that it had not progressed as far.

Examination of Quarry No. 4-6R - In the course of inspecting the Rochester bridges, Physical Research personnel were taken through Quarry No. 4-6R by Mr. George Gregg, District Materials Engineer. Particular attention was directed to the "dirty" condition of stockpiled aggregate from this source. Determinations of percent by weight of material finer than the number 200 sieve made by District personnel resulted in values well in excess of the present New York requirement of 0.7 percent maximum.

Excessive amounts of this size material are generally undesirable and are usually restricted by specifications for concrete coarse aggregate. The ASTM allows a maximum of 1 percent, or $1\frac{1}{2}$ percent if consisting primarily of non-clayey dust from crushing. Material of this size increases the water requirement of concrete and may, thereby, contribute to a decrease in durability or excessive drying shrinkage. Moreover, it may act to interfere with proper cement paste-aggregate bond.

It is not possible to state whether the "dirty" condition that was observed in the fall of 1963 also prevailed in 1954-55 when the bridges in question were built. Assuming that it did, it could have been a contributing factor to the distress that has been observed, although no direct evidence of this was found.

Summary of Field Observations - The concrete distress observed on all seven bridges inspected was generally similar in appearance. It was characterized in its initial stage by the formation of fine surface cracks. These cracks and the deterioration that followed always occurred on surfaces exposed to a concentration of water containing dissolved de-icing salts, or on relatively thin members such as wing walls. The association with unusual concentrations of water was indicated by direct observation, staining, and the presence of deposits of carbonates and chlorides as a gray or white crust on the concrete surface. The significance of the presence of de-icing salts can be judged by the generally good condition of the B & O Railroad bridge over Mt. Read Blvd. where no evidence of deterioration of the abutments was noticed, even though liberal amounts of water were observed flowing over them from above. In this case, the only source of salt was splash from the roadway onto the sidewalk retaining walls as the deck is not salted.

Concrete in which surface cracking had developed was weak and responded to the strike of a hammer with a dull sound. In its extreme, complete disintegration of the mortar had taken place from the concrete surface inward. In general, the coarse aggregate was observed to remain intact and could, in many cases, be easily picked from its matrix, although, some coarse aggregate was found that had broken down along parallel planes. This aggregate had the same physical appearance as that which was observed at the base of the few popouts noted in these same structures. Chert popouts were observed in the bridge at Batavia.

The strong association of these failures with concentrations of water (and particularly the presence of dissolved de-icing salts), the pattern of failure, and the appearance of the distressed concrete strongly suggest damage resulting from the freezing of saturated cement paste aggravated by the presence of dissolved de-icing chemicals.

The pattern of cracking that is often associated with abnormal internal expansion resulting from unsound cement or aggregate, or from chemical reaction between aggregate and cement was not observed. This type of failure is often characterized by cracks that are relatively large and widely spaced and that extend to an appreciable depth. Concrete between the cracks is usually sound and responds to the blow of a hammer with a "solid" ring. Further, no evidence of abnormal expansion of entire structural units was noted which would be characteristic of this type of problem.

The gray and white incrustations noted on many of the structures are not the products of a chemical reaction between cement and aggregates but represent, primarily, lime which has leached from the concrete and carbonated.

Examination of other bridges in the Rochester area shows that although Quarry 4-6R may be associated with the instances of worst deterioration in non-air entrained concrete, Quarry 4-4R has a greater frequency of association with distress in terms of the toal number and percent of bridges affected. Furthermore, the use of air entrainment has virtually eliminated durability problems in bridge concrete incorporating aggregate from both sources.

The bituminous wearing surfaces apparently have not effectively sealed the concrete structural deck from water, either because they have become cracked or because of their inherent permeability. Thus deterioration of structural decks beneath bituminous wearing surfaces was observed when the decks were cored.

Laboratory Studies

After the field inspection, cores were removed from bridges (1) through (5). These cores, aggregate from the quarry which supplied the coarse aggregate, and laboratory materials records were examined primarily to ascertain the possibility of chemical reaction between the aggregate and the cement paste which could have contributed to the distress that was noted.

Material Records - Table 2, below, summarizes pertinent information on the materials used for the seven bridges. Their records show that bridges (1) through (5) and bridge (7) were constructed during 1954 and 1955 with non-air-entrained concrete.

TABLE NO. 2

Bridge No.	Year Constructed	AE	Cement	C. A. Source	F. A. Source
(1)	'54 - '55	No	portland & natural	4-6R	4-10F
(2)	'54 - '55	No	portland & natural	4-6R	4-4F
(3)	'54 - '55	No	portland & natural	4-6R	4-4F
(4)	'54 - '55	No	portland & natural	4-6R	4-4F
(5)	'54 - '55	No	portland & natural	4-6R	4-4F
(6)	'57 approx.	Yes	portland & natural	4-4R	4-10F
(7)	'54 - '55	No	portland & natural	4-3R	4-2F

This fact strongly supports the argument for freezing damage as the principal cause of distress. Whether the caps on retaining walls at bridge (6) had the proper amount of entrained air could not be determined as the cap was inaccessible for coring. Equipment now being built by the Bureau of Physical Research will permit determination of air content from polished surfaces of comparatively small samples, however, this equipment is not yet operational.

The cement, in all cases was a normal, non-air entraining type mixed with natural cement in the proportion of seven bags to one. The only exception to this was the B & O Railroad Bridge in which the backwalls and curbs are thought to have included some air entraining cement. These are not the same areas, however, that were noted before as being free of distress even though appreciable amounts of water were observed flowing over them.

Source 4-6R which supplied coarse aggregate to bridges (1) through (5) and Source 4-4R which supplied coarse aggregate to bridge (6) operate in the Lockport Dolomite formation. At the time bridges (1) through (5) were constructed, the DeCew member of the Lockport was acceptable concrete aggregate. Since the Department introduced a freezing and thawing test subsequent to this construction, the DeCew has been unacceptable because it does not consistently pass this test. Its failure has been attributed to finely disseminated clay particles found throughout its mass. The DeCew is not found in the Source 4-4R quarry.

Bridge (7) incorporated coarse aggregate from Source 4-3R. This source operates in the Onondaga Limestone formation. Chert which occurs in the Onondaga Limestone from this quarry has been shown to be potentially chemically reactive with high alkali cement (Physical Research Project No. 12, Interim Report, RR 62-7) and to have a moderate porosity which could also make it susceptible to frost damage. Other bridge structures which incorporate aggregate from this same source and which are thought to be air entrained are relatively free of the type of distress noted at bridge (7) and described as a general disintegration of the cement paste. This also supports the arguement that the distress noted at bridge (7) has resulted from the freezing of non-air-entrained mortar that has become saturated with water containing dissolved de-icing salts. The few popouts which were observed could be the result of physical or chemical agents.

All fine aggregate sources noted in Table 1 produce concrete sands that are predominantly limestone and sandstone.

Studies of Concrete Cores - A total of twenty, four-inch diameter cores were obtained from bridges (1) through (5). These cores were of various lengths and were taken from both deteriorated and non-deteriorated areas. Most of the cores were tested for air content and 7-day water absorption, after which they were sawed in half longitudinally. One half was retained by the Bureau of Physical Research and one half was submitted to

the Geology Department of Rensselaer Polytechnic Institute. Table 3 summarizes the information that was collected for each core.

As noted, the concrete was made with non-air entraining cement and some natural cement. High-pressure (5000 psi) air content determinations indicated an average air content of 3.2% with a range from 2.1% to 4.5%. This amount of air was probably produced, in part, by the grinding aids used in the production of natural cement. The 3.2% average was above the minimum of 3.0% specified in the NYS DPW Specifications then in effect. However, it has been shown by various investigators that the size of the bubbles and the distance between them are actually the significant factors for frost resistance. For the same total volume, smaller bubbles closely spaced give better protection than larger bubbles more distantly spaced. It was noted that there were large, irregular voids in nearly all of the cores. This would tend to raise the air content but would be of little or no value in frost protection. The fact that some air was probably entrained by the natural cement may account for the general lack of distress noted in the abutments of the B & O RR bridge even where it was evident that a considerable movement of water had occurred.

Seven day water absorptions averaged 4.9% with a range from 3.8 to 6.2 (See Table 3). There was no consistent relationship between deterioration and any absorption values obtained.

Portions of cores retained by the Bureau of Physical Research were polished and examined under the stereomicroscope for evidences of cracking within the paste or aggregate and for evidences of chemical reaction at the aggregate-cement paste interface. With the equipment presently available to the Bureau it was not possible to evaluate those factors that would indicate the use of dirty aggregates. Similar examinations were made on the portions of cores that were forwarded to RPI. In addition, RPI determined which members of the Lockport formation were represented in each core examined.

The coarse aggregate in the cores was found to consist of pieces from the Oak Orchard, Penfield, and DeCew members of the Lockport formation. Darkened rims were noted immediately within the periphery of most coarse aggregate of DeCew lithology (Figures 10 and 11). Thinner and less distinct rims were found around some pieces of coarse aggregate from the Oak Orchard and Penfield members of the Lockport but the number of these was insignificant compared to those around the DeCew. These rims

TABLE NO. 3
RESULTS OF CONCRETE CORE EXAMINATIONS

Core No.	Bridge	Core Location	Condition of Concrete Surface	Length	% Air*	7-Day Absorption %	DeCew Present	Rims Number Observed	Staining	Etching	Internal Cracking
1	Troup St.-Howell St.(1)	Pier"F"Footing	Good, water stained	11"	3.7	5.7	Yes	> 20	-	Neg.	Neg.
2	"	"	Good	4"	-	-	"	-	-	-	"
3	"	"	Cracked and water stained	11"	2.5	6.0	"	10-20	-	-	"
4	"	Deck	Deteriorated, fragments retrieved	-	-	-	-	-	-	-	"
5	"	"	Deteriorated, not retrieved	-	-	-	-	-	-	-	"
6	NYC RR (2)	Median Island	Scaled and water stained	11"	3.6	4.7	"	0-10	-	-	"
7	"	"	Good	10½"	3.9	4.3	"	0-10	-	Neg.	"
8	"	"	Cracked	10"	3.5	3.8	"	> 20	-	"	"
9	"	E. Sidewalk	Cracked	10"	4.5	-	"	0-10	Neg.	"	"
10	"	"	Cracked	2-5"	3.1	6.2	"	0-10	-	-	"
11	"	S. Abutment	Cracked and water stained	3½"&7½"	3.2	3.9	"	> 20	-	Neg.	"
12	B & O RR (3)	E.Retaining wall	Good, water stained	2-5"	2.8	5.8	"	-	-	"	"
13	"	E. Abutment	Good, water stained	6"	3.1	3.9	"	0-10	-	-	"
14A	"	NW Wingwall	Cracked	5"	2.8	-	"	10-20	-	-	"
14B	"	"	Cracked	5"	2.1	-	"	10-20	Neg.	Neg.	"
15	Ridgeway Ave. (4)	Deck	Deteriorated	5"	4.0	-	"	-	-	-	"
16	"	NW Wingwall	Cracked, fragments retrieved	-	-	-	-	-	-	-	"
17	"	SW Wingwall	Good	12"	2.3	4.2	"	0-10	Neg.	-	"
18	Ridge Rd. (5)	Deck	Deteriorated	7"	3.0	-	"	10-20	-	-	"
19	"	"	Good	10"	2.9	-	"	-	-	-	"

*These values were determined by high-pressure air meter and represent total air contents, including entrapped cavities of which a number were noted. The volume of entrained, or useful, air would be less.

Figure 10 - Longitudinal cross section of core showing typical rimmed aggregates.

Figure 11 - Enlargement of rimmed aggregate shown circled in Figure 10.

are similar in appearance to those noted in the literature to be associated with the recognized carbonate aggregate reactions.

The microscopic examination of cores by the Bureau and by RPI revealed no cracking within the cement paste. Some fine fracturing within pieces of the DeCew aggregate was noted in most of the cores, however, no evidence was found that this had caused any distress in the surrounding paste.

After the microscopic examination, the concrete surfaces were etched with dilute hydrochloric acid as an aid in detecting evidence of silicification. This reaction has been observed, by other investigators, in concrete containing certain carbonate aggregates, and is characterized by the development of silicious rims in the periferal zone of the aggregate. It has been suggested that this reaction results in the deterioration of concrete by removal of silica from the cement paste adjacent to the susceptible aggregate. Acid etching of effected concrete, will produce deep trenching in the silica-depleted zone of the paste and leave a resistant, silica-rich aggregate rim. The acid etching of cores was performed both by the Bureau of Physical Research and by RPI. Etching did not accentuate any of the rims that had been previously observed. Nor did it produce any noticeable trenching of the paste adjacent to rimmed aggregate particles.

Selected cores were stained at RPI to illustrate non-uniform distribution of calcite within aggregate particles which would be an indication that dedolomitization had occurred. The dedolomitization of aggregates in concrete has been referred to as the alkali-carbonate rock reaction to differentiate it from the alkali-aggregate (or alkali-silica aggregate) reaction which has been recognized primarily in the central and western United States for some years. Dedolomitization has been observed in concrete containing certain argillaceous dolomites and involves a chemical reaction between the dolomite and cement alkalies producing calcite and other products, the volume of which exceeds the volume of the original reactants. It is this increased volume of the reaction products that is thought to produce distress in the affected concrete. The staining that was performed produced no evidence of chemical action.

Studies of Coarse Aggregate from Source 4-6R - The Lockport Dolomite formation has been under study at RPI under the provisions of a contract with the Bureau of Physical Research. Included in this study have been aggregates sampled from all members of the formation where they outcrop in the Source 4-6R

quarry. Samples taken from all quarries operating in the Lockport formation were subjected to petrographic analysis and tests to measure their potential for dedolomitization. The dedolomitization test consists of immersing small shaped rock specimens in an alkaline solution and periodically measuring their change in length. A significant change in length is interpreted as indicating that dedolomitization has taken place.

The characteristics that have been noted in carbonate rocks which experience the dedolomitization reaction in concrete are: (1) A nominal ratio of dolomite to total carbonates of 1:1, (2) a high insoluble residue composed largely of clay minerals, and (3) a texture described as isolated euhedral (with well formed faces) dolomite rhombs in a fine calcite matrix. Studies of the Lockport dolomite formation by RPI indicate that none of the individual members approach the above carbonate ratio or textural characteristics and only the DeCew member consistently shows high insoluble residues. None of the samples from any of the Lockport members including the DeCew, expanded appreciably in alkaline solutions, which suggests a lack of potential for dedolomitization.

The fact remains, however, that darkened rims were noted in a large number of pieces, primarily of the DeCew lithology. These rims were found with equal frequency in cores from damaged and undamaged areas and did not appear to be associated with any recognized distress. Their presence remains unexplained but further attempts are being made to identify them.

Aggregate of the DeCew lithology was noted in many instances to be internally fractured. This fracturing had not resulted in complete disintegration of the aggregate and did not appear to be associated with any distress in the cement paste.

Neither the coarse nor the fine aggregate are of the type that would make them susceptible to the alkali-silica aggregate reaction.

Conclusions

The conclusions drawn in this report stem principally from studies of the first five bridges and, therefore, relate largely to them. Certain similarities between these and the other two, however, allow some of these conclusions to be extended to all the structures investigated. Bridges (6) and (7) are currently

being studied more thoroughly in connection with inspections of all concrete incorporating coarse aggregate from the Lockport and Onondaga limestone formations, respectively.

1. The principal cause of distress is freezing of non-air entrained concrete which has been saturated with water frequently containing de-icing salts.

2. It does not appear that a chemical reaction has occurred between cement and aggregates that has been harmful to the concrete, with the possible exception of a few chert popouts in the Batavia bridge. These popouts, however, have not contributed to the cement paste deterioration observed at this site.

3. The DeCew lithology may have contributed, in a minor way, to the observed distress by causing popouts on the surface of highly saturated concrete as a result of their lack of soundness upon wetting or freezing.

RECOMMENDATIONS

1. Air entrainment near the upper limit permitted by our specifications should be utilized in all exposed concrete.

2. All efforts possible should be made during the design, construction and maintenance of bridges to channel runoff in a way that it avoids as much of the structure as possible. This is important, even when air entrained concrete is used, as a hedge against normal variations in the desired level of air content or instances where unsound aggregate may exist close to the surface.

3. Aggregate from the DeCew member of the Lockport formation should continue to be restricted from use in portland cement concrete.

4. As for methods of remedying the condition of the bridges which have been studied, patching or replacement of deteriorated concrete is recommended

together with efforts to limit the access of water to the under structure and other distressed areas by sealing the concrete surface and by devising alternate methods of draining the deck. It is suggested that the Bridge Subdivision be consulted on the most satisfactory means of accomplishing this.